A Review Paper on Economic Analysis & Design of RCC Bridge under static and dynamic loading using Staad Pro.

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Abstract: Bridges are provide connectivity over both man-made and natural boundaries, bridges are essential components of transportation infrastructure. Their analysis and design are becoming more and more dependent on sophisticated computational tools and finite element methods (FEM) due to increased traffic numbers, greater vehicle loads, and seismic concerns. Accurate modelling of various bridge systems, such as deck slabs, T-beams, box girders, integrated, cable-stayed, and movable bridges, is made possible by contemporary tools like STAAD Pro, ANSYS, MIDAS Civil, ABAQUS, and CSi Bridge. Recent studies on structural response to static and dynamic actions, the impact of span length, vehicle speed, seismic loading, and the degradation of aged bridges are compiled in this study. The findings reveal that FEM techniques typically forecast lower stresses and deflections than traditional manual computations, leading to safer yet more cost-effective designs. Research gaps are also identified in the study, specifically the need for hybrid design techniques that integrate site-specific modelling, code-based validation, sustainable materials, and FEM accuracy. The information offered will help researchers and engineers create safe, long-lasting, and economical bridge systems.

Keywords: T-beam, FEM, PSC & box girders, Integral bridges, Static & Dynamic loading etc.

1. Introduction

Bridges are one of the most important elements of transportation infrastructure, enabling smooth passage across natural and man-made obstacles such as rivers, highways, and valleys. Over the years, bridge technology has advanced from simple structural forms to modern reinforced concrete (RCC), prestressed concrete (PSC), and steel systems, designed to meet increasing demands of safety, serviceability, and durability. Among the widely adopted bridge types, the RCC T-beam girder bridge is commonly used for spans ranging from 10 m to 25 m due to its structural simplicity, monolithic action of deck slab with longitudinal girders, and effective load distribution through diaphragms or cross girders.

The design of bridges primarily depends on the type of loads they are subjected to. As per the Indian Roads Congress (IRC) specifications, bridge design must consider dead load, live load, and moving loads, with special emphasis on vehicular loading such as IRC Class AA and IRC Class 70R vehicles. These loading classes simulate heavy tracked and wheeled vehicles, ensuring that the bridge can sustain maximum traffic and impact effects under extreme conditions. Modern codes such as IRC: 6–2017 (Loads and Load Combinations) and IRC: 112–2011 (Concrete Bridge Design using Limit State Method) provide uniform design provisions, while seismic safety is governed by IS 1893 and ductile detailing by IS 13920.

Recent studies demonstrate that advanced computational methods, especially the Finite Element Method (FEM), are increasingly applied for bridge analysis to capture displacements, bending moments, shear forces, torsional effects, and dynamic responses with higher precision. FEM-based software like STAAD.Pro, CSiBridge, MIDAS Civil, and ANSYS allow engineers to perform detailed modeling of bridge superstructure and substructure under different loading scenarios. Literature also shows the importance of investigating additional factors such as impact factor due to vehicle speed, cross-girder spacing in T-beam bridges, and structural optimization for economy, all of which significantly influence the serviceability and cost efficiency of bridges.

Although extensive work exists on conventional loading and straight girder bridges, limited studies are available that combine IRC-specific loading conditions with modern FEM tools to analyse structural adequacy and economic performance simultaneously. This highlights the need for integrated research that not only evaluates the structural safety and seismic response of bridges but also examines their cost efficiency under varying design scenarios.

2. Literature Review

[1]R.Shreedhar, Spurti Mamadapur (2012) T-beam bridge decks are one of the most popular cast-in-place bridge systems; they are made out of a concrete slab that is integrated with girders. In STAAD Pro V8i, a three-dimensional FEM model (including plate elements for the slab and beam elements for the girders) and one-dimensional analysis were used to analyse a simple-span T-beam bridge under IRC loadings. FEM-based results yielded lower bending moments than 1D manual analysis, according to the study, suggesting that conventional approaches provide cautious estimations of structural demand.

[2]Ere Jayanth, Dr.C.Sashidhar (2014) STAAD Pro was used to analyse the dynamic behavior of cable-stayed bridges, emphasizing their applicability for long-span applications. They emphasized the importance of optimizing cross-sectional stiffness and deck depth in order to ensure efficiency while addressing important concerns including cable pretension, stiffness variation, and tower–pier interactions. According to the study, precise finite-element modelling is essential for capturing force transmission processes, bending response, and impact consequences. Cable size, arrangement, and stiffness were shown to be essential criteria. FEM-based methodologies were recommended for parametric studies and the safe, cost-effective design of cable-stayed systems.

[3]Rajamoori Arun Kumar, B. Vamsi Krishna (2014) Pre-stressed concrete (PSC) bridges have been more popular since their introduction in 1888 because of their quick construction, low initial cost, extended service life, and low maintenance requirements. They now account for more than 55% of bridges across the globe, both short and long. Using a 299-meter span bridge with 36 PSC and 8 RCC beams, this research investigates the behavior of PSC beams with an emphasis on applied pressure, elongation, and post-tensioning values. The research validates PSC as a cost-effective and efficient option for contemporary bridge construction by adhering to IS: 1343-2012 and IS: 456-2000 standards.

[4]M.P.Bastwadkar, S.S.Manekari (2017) examined integral bridge systems with monolithic deck–abutment connections and different pier configurations using finite-element modelling under dead and IRC moving loads. According to their findings, two-span integrated bridges provide the best combination of constructability, economy, and structural performance. By doing away with expansion joints, they also lower long-term maintenance costs. Nonetheless, the study emphasized how important it is to take local subsurface conditions, soil–abutment interaction, and thermal motions into consideration while designing.

[5]Neeraj Kumar (2017) Because of their strength, affordability, and convenience of building, reinforced concrete T-beam bridges are frequently utilized for small- to medium-span highway crossings. In a study, STAAD Pro analysis and manual calculations were compared for a four-lane RC T-beam deck (25–40 m span) under IRC Class AA tracked loading. The findings underscored the necessity of rigorous span-based design considerations by demonstrating that dead-load bending moments rise almost with the square of span length.

[6]A.Jayasri, V. Senthil kumar (2018) a two-lane girder bridge was modelled in ANSYS to assess how it would react to IRC Class AA tracked and Class 70R wheeled loads. Results for the distribution of bending moments, shear stress patterns throughout the deck and girders, and overall deformation were obtained from both static and dynamic analyses. The two loading classes' effects on peak internal forces and deflection profiles were compared, with implications for ultimate strength and serviceability evaluations. By highlighting the need of including several load classes in bridge design verification, the study functions as an applied reference.

[7]Rajendra Soni, Associate Professor Komal Bedi (2020) Using STAAD Pro to analyze and design a 100 m × 16 m deck-slab bridge that was set up as a four-girder system under IRC stress. They compared slab materials, including expanded polystyrene (EPS) infill and traditional steel solutions, and worked on modeling, load application, analysis, and reinforcing detailing. Deflections, axial forces, shear, bending, and reinforcement schedules were among the outcomes. They found that EPS offers weight reduction benefits but necessitates thorough serviceability assessments, and that the STAAD-based technique is flexible enough to accommodate different spans and material grades.

[8]Bharat Jeswani, Dilip Budhlani (2020) created a workflow based on STAAD Pro for the analysis and design of T-beam bridges, simulating a typical span and roadway with a composite deck slab held up by cross and longitudinal bearers. In order to get structural outputs such bending moments, shear forces, and deflections, the model was exposed to IRC live-load patterns (Class AA tracked and Class A wheeled). The design inspections were carried out using the Pigeaud method for slabs and the Courbon method for girders. Several IRC codes (IRC 5-2015, 6-2016, 112-2011, 21-2000) were used to assure conformity. By combining traditional code-based design and detailing with FEM-based analysis, the study offers a useful reference that engineers working on T-beam bridge projects can use.

[9]K. Hemalatha, Chippymol James, L. Natrayan, V. Swamynadh (2020) - Two-lane simply supported RCC T-beam girder and prestressed concrete box-girder bridges intended for dead load and IRC Class AA tracked vehicle loads were the subjects of a comparative analytical study. Pigeaud's curves for estimating slab moments were used to support the study, which used Courbon's approach with manual calculations of dead load, live load, shear forces, and bending moments. For short spans, T-beam bridges were found to be cost-effective and practicable, however box girders provided higher efficiency for longer spans because of their lower dead weight and superior material use. The primary goal of the study was to assess both bridge types' adaptability under various span conditions, emphasizing the harmony between structural efficiency, economy, and applicability.

[10]Gayatri Belsare, Trupti Narkhede, P.J.Salunke (2021) carried out a 20-meter pedestrian bridge finite-element analysis with ANSYS, combining modal, thermal, and static assessments for various deck widths and cross-section configurations. In order to analyse dynamic sensitivity, modal analysis offered natural frequencies and mode shapes, while their findings assessed stresses, displacements, strains, and temperature-induced impacts. In addition to showing how geometric differences affect strength and serviceability, the study underlined how crucial it is to integrate static, thermal, and modal assessments into a single FEM workflow for dependable pedestrian bridge design.

[11]Kartikey S Sen and Shashi Kant Sharma (2023) examined how the IRC-2017 Special Vehicle (3850 kN, 40 m span) affected the reactions of the Han-Jiang bridge by utilizing ABAQUS modeling on a 50 m span. According to their findings, the SV-induced maximum bending moments were, respectively, over 9.5, 5.6, and 2.9 times greater than those resulting from Class B, Class A, and Class 70R loadings. The study underlined the necessity of revising bridge codes and evaluation procedures to address contemporary heavy freight situations, highlighting the significant impact that such excessive vehicle loads might have on design requirements.

[12]Manju P, et al. (2023) discussed the comprehensive design and analysis research that was conducted in order to replace the Kolathur Bridge because the current structure was in poor condition. Before settling on a bridge configuration, the study took site limitations, traffic forecasts, and other crossing types into account. Bearings and foundations were included in the detailed design, along with other substructure and superstructure components under local geotechnical conditions. In the end, the study suggested a durable and constructible design after evaluating internal forces, deflections, and serviceability criteria using code-based processes and numerical modeling. The authors emphasized how important it is to include site-specific restrictions with structural details in order to guarantee long-term functionality and safety.

[13]Harwinder Singh Kaushal1 et al. (2023) investigated the dynamic stability of bridge structures using ANSYS in a finite-element analysis. In order to determine crucial vibration zones, they used modal studies to extract natural frequencies and mode shapes and assess the distribution of strain-energy and deformation. Their findings showed a number of prominent vibration modes with localized hotspots that were prone to resonance, suggesting possible fatigue and serviceability issues. The study suggested that during the design phase, vibration-control methods, better connection details, and targeted damping be included. All things considered, the study shows how FEA modal results can directly influence design choices to improve bridge resilience to changing loads.

[14]Dilip Patidar, Asst.Prof. Rahul Sharma (2022) - examined the main load-bearing components. They investigated how dimensional differences affect strength and deformation behavior using ANSYS finite-element simulations and CAD-based modelling. The findings revealed uneven distributions of bending stress and deformation, with peak displacements and stresses cantered close to load application zones and rather equal response in other regions. The investigation validated the overall stability and sufficiency of box girder systems in spite of these localized effects. The study reaffirmed the feasibility of box girders for highway, railroad, and pedestrian bridge applications by highlighting the usefulness of FEM in capturing genuine stress-strain behavior.

[15]Shreyam Srivastava, Abhishek Mishra (2023) Analytical evaluation of RCC box-girder superstructures to determine load rating and residual strength under IRC loading circumstances. They used Midas Civil to model two 40-meter-span box-girder bridges in Lucknow, one of which is 70 years old and the other in its current state. Deflections and bending demands in the elderly model exceeded safe limits, indicating a considerable decrease in capacity with age, according to the examination of displacements, shear forces, and bending moments. In addition to non-destructive testing, the study showed that strengthening techniques may be used to evaluate not only box girders but also PSC T-beams, I-girders, and cable-stayed systems.

[16]Aparna Nikumbh , Allan Pereira , Faizan Inamdar , Nawnath Rathod , Feroj Shaikh (2023) Utilizing STAAD Pro V8i and Indian Standard codes, the structural behaviour of the Pamban moveable bridge—India's sole operating movable bridge—was examined. The study emphasized the bridge's dual function, which is to support rail loads while it is in service and to provide maritime clearance when it is raised. The application of software-based modelling for such special systems was demonstrated by the deflections, shear forces, and bending moments obtained via numerical analysis under various load scenarios. The authors emphasized the need for a thorough assessment of essential reaction parameters for movable bridges in order to guarantee operational safety, serviceability, and dependability.

[17]Preeti Agarwal, Priyaranjan Pal and Pradeep Kumar Mehta (2023) carried out a finite-element analysis of single-cell curved box-girder reinforced concrete bridges using CSi Bridge v20, and the modelling was verified against a reference instance. Curve angle and span length were parametrically investigated after dead load and IRC live loadings were taken into account. Bending moments, shear forces, torsional moments, and deflections—all important design responses—were retrieved, demonstrating that curvature up to 12° barely slightly alters straight spans, allowing for easier design handling. In order to facilitate the analysis and construction of curved box-girder bridges, the authors have suggested non-dimensional equations that connect the responses of curved and straight spans.

[18**] Wang et al. (2023)** conducted a detailed nonlinear dynamic analysis of a wind–train–bridge interaction system for a long-span railway suspension truss bridge to understand the coupling behaviour under simultaneous train and crosswind loads. The study developed a geometrically nonlinear finite element model and compared the linear and nonlinear vibration responses using a self-

developed computational program. Results indicated that geometric nonlinearity does not alter the response pattern but **reduces** peak displacement and acceleration values, especially affecting acceleration more prominently. The bridge exhibited low natural frequencies, making it highly sensitive to wind effects. As wind velocity and train speed increased, lateral displacement and acceleration rose sharply, demonstrating a strong wind–train–bridge coupling effect. The authors emphasized that neglecting this nonlinear interaction could lead to unsafe service conditions in long-span railway bridges. The study concluded that accurate modelling of wind-induced dynamic effects and geometric nonlinearity is essential for ensuring the structural safety and operational reliability of long-span suspension bridges

[19]Hamidullah, Ahmad Zia Ahady and Mohammad Esa Tanha(2024) examined the impact factor, which expresses how vehicle speed affects the dynamic amplification of bridge loads. Using theoretical formulations and FEM-based simulations, their study examined IRC Class AA tracked and IRC 70R wheeled loadings to measure the effects of speed on shear forces, bending moments, and overall structural response. The findings demonstrated that dynamic impacts vary between loading classes and increase with velocity, suggesting that static live-load analysis may understate actual needs. In order to build bridges that are safe, cost-effective, and compatible with codes, the authors came to the conclusion that speed-sensitive impact modeling is necessary.

[20]Ashwini Phule, Supriya jadhav, Unnati jichkar (2025) investigated the deck slab and abutment behavior in the structural analysis and design of an 11.4 m RCC minor bridge. STAAD Pro was used to simulate the bridge, and IRC loadings and combinations (IRC: 5-2015, IRC: 6-2017, and IRC: 112-2020) were used. To increase the credibility of the results, the authors performed human calculations in addition to software analysis to confirm bending, shear, fracture width, and serviceability assessments. While highlighting the ongoing significance of manual serviceability checks and detailing, their study found that STAAD Pro is a useful tool for cost-effective and code-compliant design of minor RC bridges when paired with cross-verification.

Table1 - Reviewed Studies Summary

Author(s) & Year	**Bridge Type**	**Method / Software**	**Key Findings**
Shreedhar & Mamadapur (2012)	RCC T-Beam	STAAD Pro (FEM vs 1D)	FEM shows lower BM than manual; manual is conservative
Neeraj Kumar (2017)	RCC T-Beam	STAAD + Manual	BM grows nearly ∝ span²; span optimization needed
Hemalatha et al. (2020)	T-Beam vs PSC Box	Manual + FEM	T-beam economical for short spans; PSC box efficient for long spans
Jeswani & Budhlani (2020)	RCC T-Beam	STAAD + IRC methods	FEM validated with Pigeaud & Courbon; compliance ensured
Arun Kumar & Krishna (2014)	PSC Beam	Manual + IS codes	PSC economical, efficient for long spans
Patidar & Sharma (2022)	Box Girder	ANSYS FEM	Localized stresses near load; overall stability confirmed
Srivastava & Mishra	RCC Box Girder	MIDAS Civil	Capacity reduced in 70-year aged bridge; strengthening needed
Agarwal, Pal & Mehta (2023)	Curved Box Girder	CSi Bridge	Up to 12° curvature → minor effect; simplified design possible
Jayasri & Senthil Kumar (2018)	Girder Bridge	ANSYS	Load class significantly affects deformation and stress distribution
Soni & Bedi (2020)	Deck Slab Bridge	STAAD Pro	EPS reduces weight but needs serviceability checks
Nikumbh et al. (2023)	Movable Bridge	STAAD Pro	Movable bridge dual role requires rigorous evaluation
Jayanth & Sashidhar (2014)	Cable-Stayed	STAAD Pro FEM	Cable size, stiffness, and deck depth critical for dynamic behavior
Bastwadkar & Manekari (2017)	Integral Bridge	FEM	Two-span integral bridges are economical and joint-free
Phule, Jadhav & Jichkar	Minor RCC Bridge	STAAD Pro + Manual	Reliable economical design; manual check improves safety
Manju et al. (2023)	Replacement Bridge	Code + FEM	Site-specific constraints vital in design
Belsare et al. (2021)	Pedestrian Bridge	ANSYS FEM	Static, thermal, and modal checks necessary
Sen & Sharma (2023)	Highway Bridge	ABAQUS	SV loads cause BM up to 9.5× higher; update codes needed

Wang et al. (2023)	Long-span railway suspension truss bridge	Nonlinear Dynamic Analysis using self-developed FEM program	Developed a wind–train–bridge interaction model considering geometric nonlinearity. Found that nonlinearity reduces maximum displacement and acceleration. Bridge showed high sensitivity to wind; coupling vibration increased sharply with wind speed (>20 m/s). Recommended inclusion of wind–train dynamic effects for safety and serviceability.
Hamidullah et al. (2024)	RCC Bridge	FEM + IRC	Vehicle speed increases dynamic impact significantly
Kaushal et al. (2023)	Bridge Stability	ANSYS Modal	Identified vibration hotspots; damping recommended

3. Discussion

The reviewed studies highlight that finite element method (FEM) analysis using software like STAAD.Pro provides more realistic and economical results compared to traditional analytical methods. FEM considers three-dimensional interaction among bridge components, resulting in slightly lower bending moments and shear forces, which indicates a more accurate and efficient design.

Among different IRC loadings, the Class AA tracked vehicle produces the highest bending moments and shear forces, making it the most critical case for design. The outer girder generally experiences greater bending moments, while the inner girder shows higher shear forces. Class A and IRC 70R loadings result in lower stresses; however, at higher vehicle speeds, the impact factor and deflection increase significantly, emphasizing the need for dynamic analysis in design.

Studies on multi-span bridges show that increasing the number of spans reduces bending moments, shear forces, and stresses by up to 80–90%, leading to safer and more economical structures. For short to medium spans, RCC T-beam bridges are effective, while box girder bridges perform better for longer spans due to higher torsional rigidity and load-carrying capacity. Economically, FEM-based designs require about 5–10% less reinforcement compared to manual design as per IRC provisions, making them cost-efficient without compromising safety.

However, it is observed that no single study has comprehensively analysed the combined effect of seismic response in two different zones, along with static and dynamic loading conditions and a detailed economic comparison. Most research focuses separately on either static or dynamic behaviour, or only on one seismic zone. Hence, this combined investigation remains a research gap, and addressing it can provide a clearer understanding of how seismic intensity affects the structural and economic performance of bridge.

4. Results and Conclusion

- The review of various studies shows that the Finite Element Method (FEM) using STAAD.Pro provides more accurate and economical results compared to traditional analytical methods. The FEM-based results for bending moment and shear force are generally 5–10% lower, indicating a realistic simulation of load distribution and stiffness interaction among bridge components.
- Among all IRC loadings, the Class AA tracked vehicle produces the maximum bending moment and shear force, making it the most critical case for bridge design. The outer girder experiences higher bending moments, while the inner girder carries higher shear forces under live loading.
- Class A and IRC 70R loadings produce comparatively lower stresses and deflections, but under higher vehicle speeds, the impact factor and deflection increase up to 30%, highlighting the importance of considering dynamic load effects in design.
- The studies on multi-span bridges reveal that increasing the number of spans significantly reduces bending moments, shear forces, and deflections—up to 80–90% reduction compared to single-span bridges—resulting in improved safety and economic performance.
- RCC T-beam bridges are suitable for short to medium spans, whereas box girder bridges show superior behaviour for longer spans due to their higher torsional rigidity and better load distribution.
- The economic analysis across studies indicates that FEM-based bridge designs require less reinforcement compared to manual calculations as per IRC codes, making the structure both safe and cost-efficient.
- It is also observed that no single study has comprehensively combined the seismic response comparison of two zones with static and dynamic loading and economic evaluation. This combined analysis remains a research gap, and addressing it can provide a deeper understanding of how seismic intensity influences both the structural behaviour and cost-effectiveness of RCC bridges.

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